Design Considerations and Performance Evaluation of a 50 kW, 40 kHz DAB Converter with Coaxial Winding Transformer

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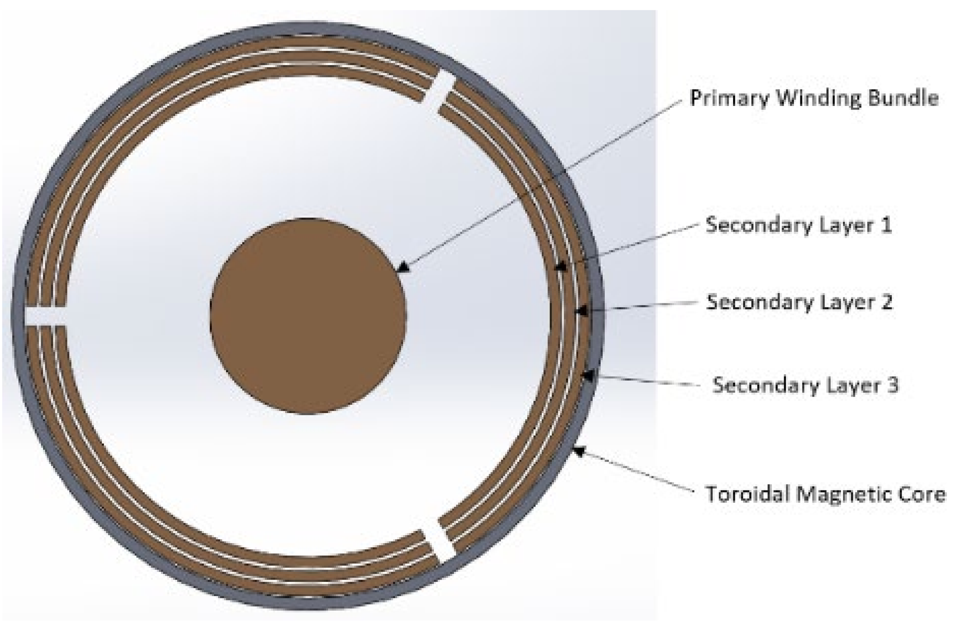
Problem Statement

Design of power electronic systems is often done with top-down specifications for each subsystem, which leaves system-level tradeoffs between power electronics, magnetics, control strategies invisible to the design process. A 50kW dual active bridge converter utilizing a coaxial winding transformer (CWT) is used to demonstrate this as a whole system co-design. Novel modeling and of coaxial winding transformers allows reduced capacitance and enhanced turns ratio options compared to previous work [1][2][3].

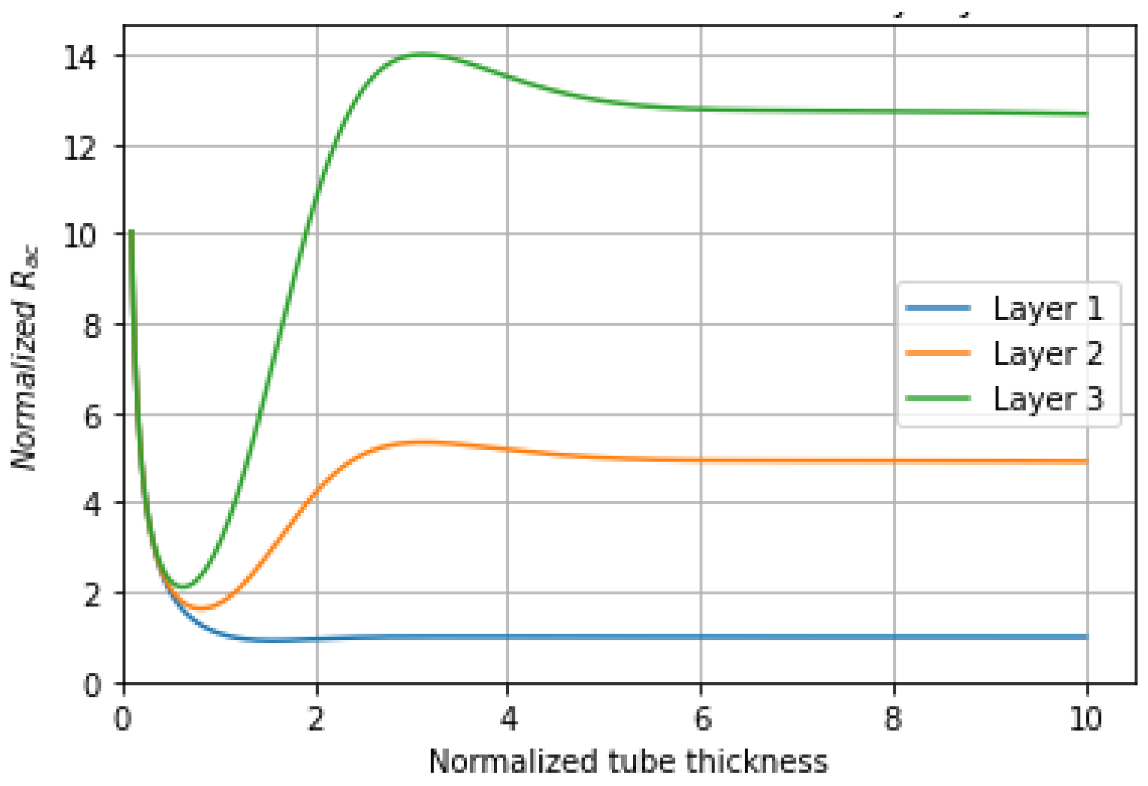
Solution

The CWT is constructed similarly to a coaxial cable and shares the benefit that fields are confined inside the tube. The leakage flux flows in the interwinding space allowing for easily-designable leakage inductance.

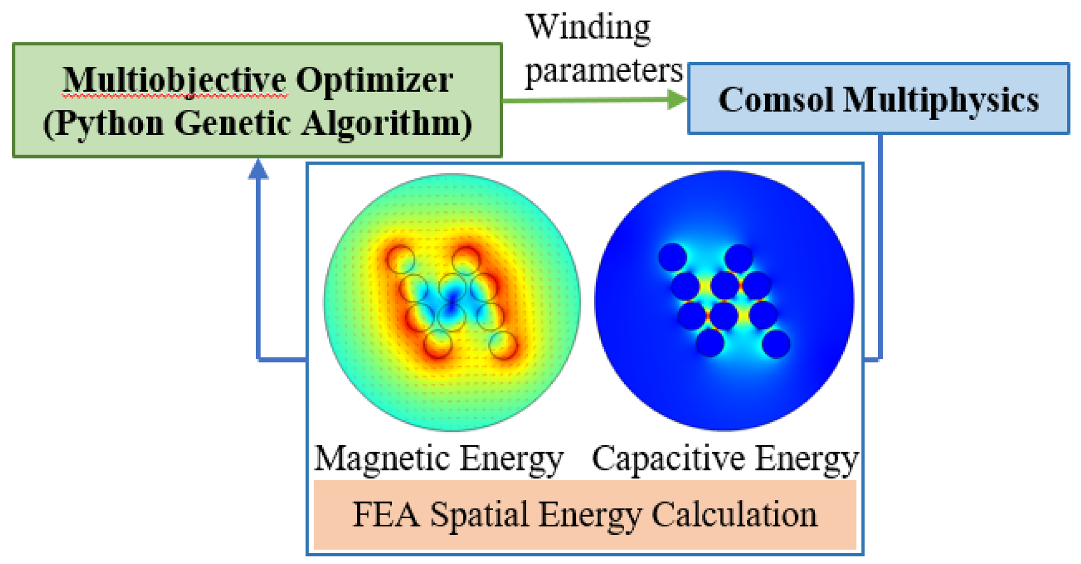


$$R_{sec} = \sum_{n}^{N} R_{ac,n} \cdot \frac{s^2 l}{\sigma\pi(r_{o,n}^2 - r_{i,n}^2)}$$

The current density in the outer winding can be solved using the differential equation above, resulting in optimal thicknesses for each layer [4]. The optimality is weak for the first layer, but stronger for each successive layer with increasing resistance.



Previous work had made some effort to reduce the capacitance of the central winding by using layered or spiral approaches, but little effort has been made to optimize CWT center winding capacitance [2]. It is observed that by bunching the turns in the center of the transformer, capacitive stored energy and electric field stress increases, but leakage inductance also increases due to the increases area surrounding the conductors. There is therefore a tradeoff between leakage inductance and capacitive stored energy that we investigated by coupling a genetic algorithm solver with COMSOL Multiphysics.



Results

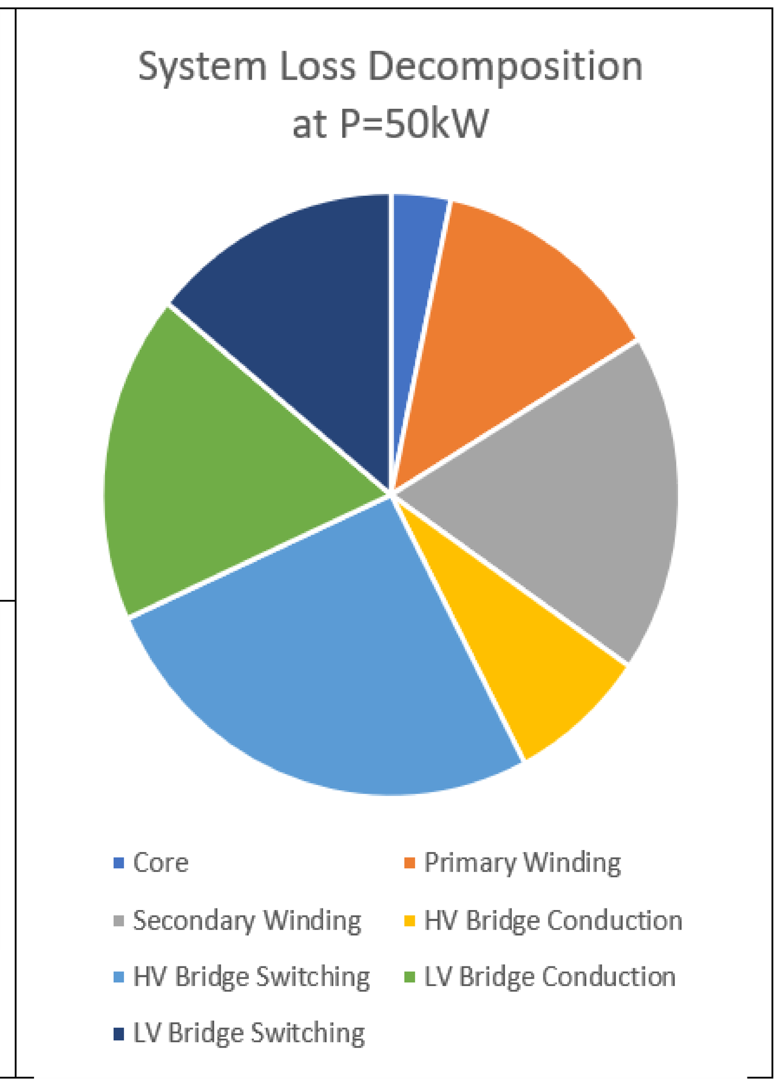
The transformer models for capacitance, inductance, winding loss, core loss, were combined with models for device conduction and switching loss, heat sink scaling, and DC link capacitors to be optimized together in a single system-level optimization using a genetic algorithm-based solver based on NSGA-II [5]. The selected design did not represent the highest power density of all options, but de-risked the construction of a CWT with many-layered foil windings.

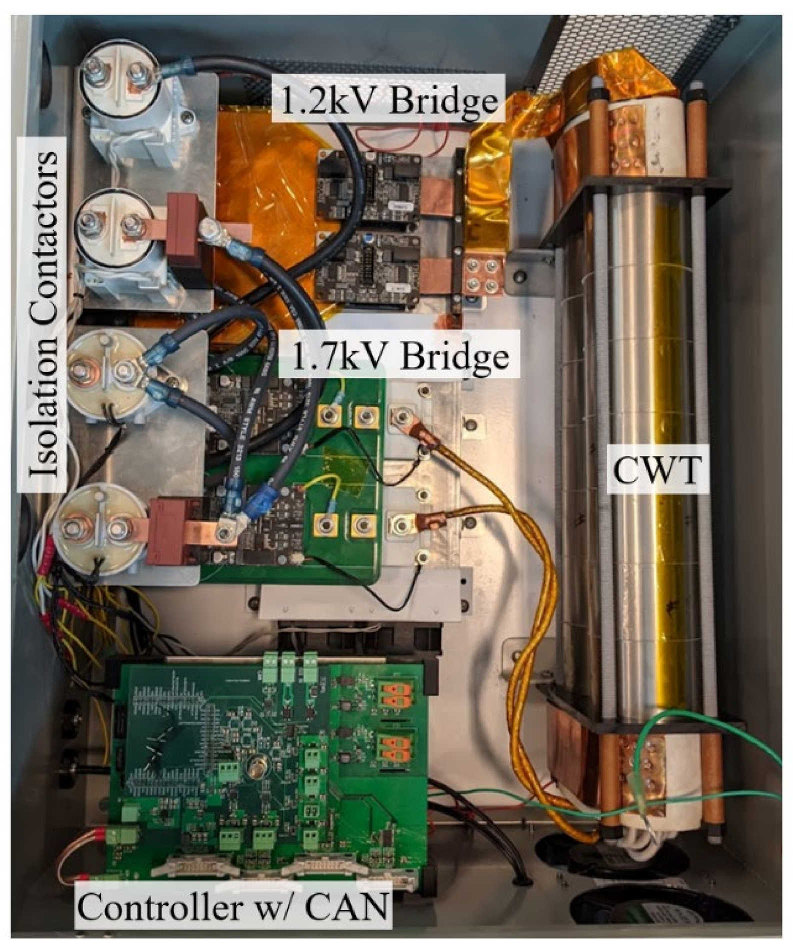
Rated Power	50 kW
Maximum Phase Shift	30 deg
Switching Frequency	40 kHz
HV Bus Voltage	1000 V
LV Bus Voltage	400 V
HV Modules	Wolfspeed CAS300M17BM2
LV Modules	Wolfspeed CAB425M12XM3
LV Capacitance	200 µF
HV Capacitance	80 µF
Transformer Turns	15:6
Transformer Leakage Inductance	34.7 µH
Transformer Magnetizing Inductance	30.0 mH

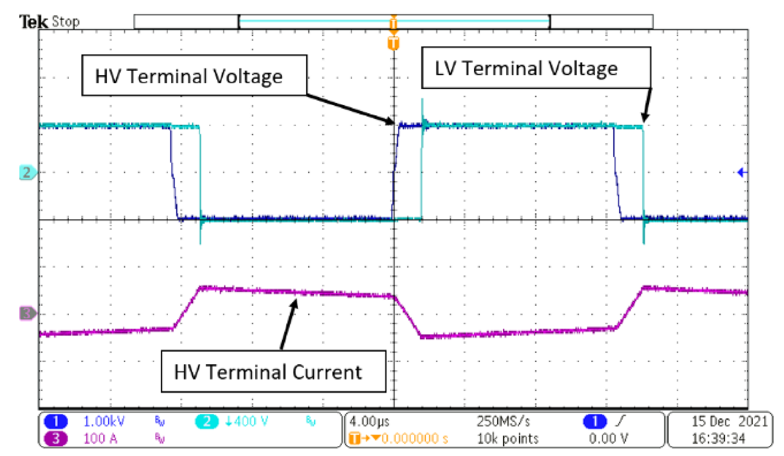
System Parameters

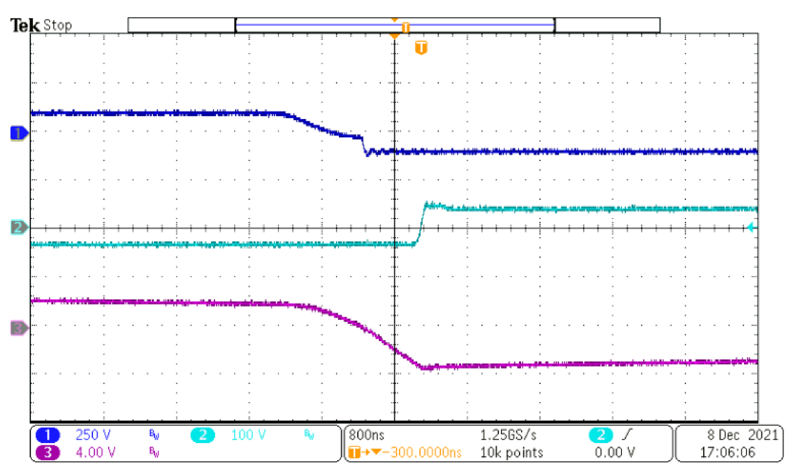
Primary Turns	15
Primary Conductor	1650x38 ga Litz
Secondary Turns	6
Secondary Layers	2
Secondary Layer 1 Conductor	10 mil copper foil
Secondary Layer 2 Conductor	20 mil copper foil
Core Inner Diameter	70 mm
Core Outer Diameter	73 mm
Core Total Length	700 mm
Core Mass	1.68 kg

Transformer Build Details



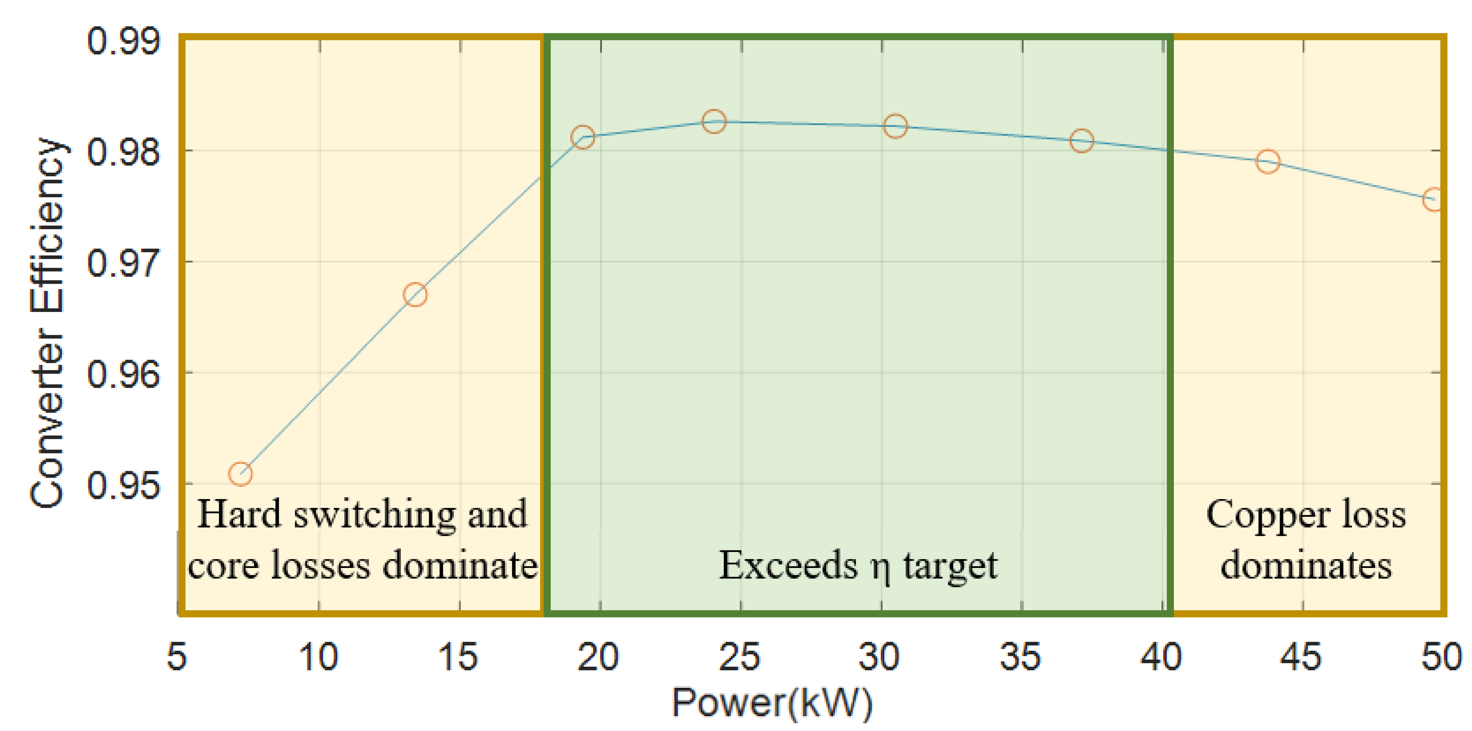




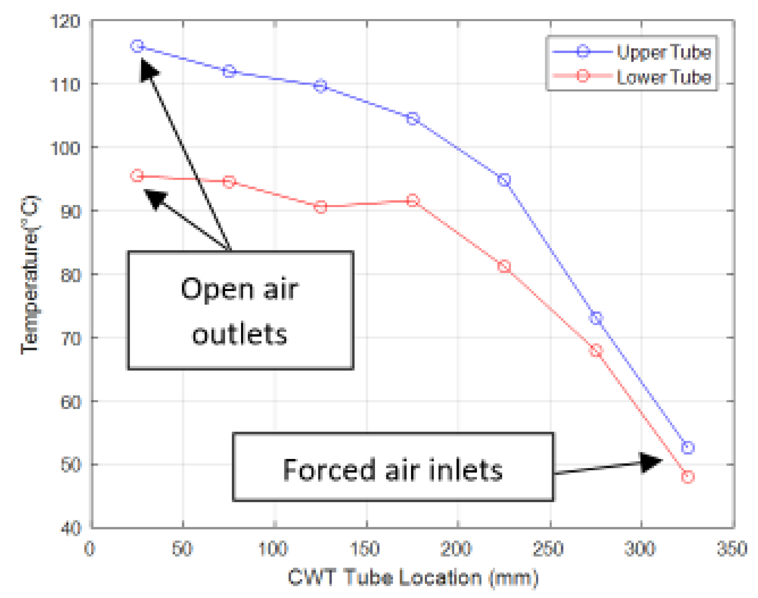


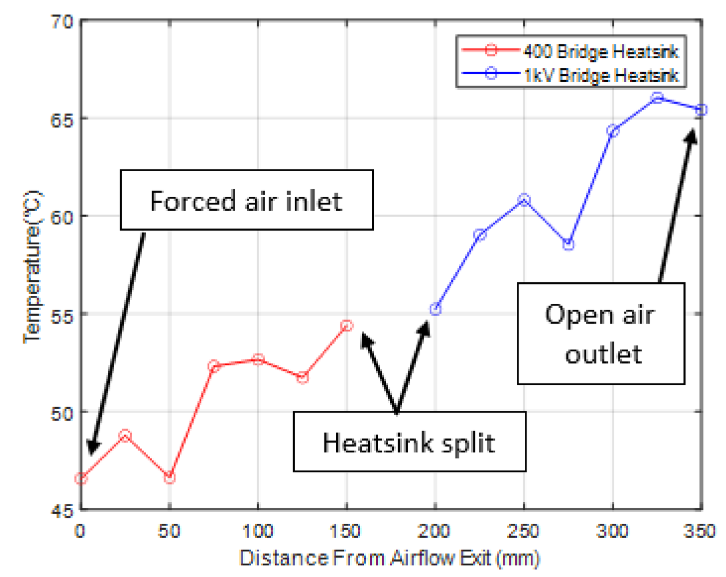
Conclusion

The converter meets the 98% efficiency target over a wide operating range. Conduction loss in the long CWT windings dominates near max power.



Thermal performance was confirmed with a LUNA ODiSI fiber-optic temperature interrogator to capture numerous temperature points even in the hostile electromagnetic environment inside the CWT tubes. Performance was as-modelled with the exception of temperature mismatch due to uneven cooling airflow in the CWT tubes.





References

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